# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. REPORT DATE** *(DD-MM-YYYY)*
16-03-2007

**2. REPORT TYPE**
Phase II STTR Final Summary Report

**3. DATES COVERED** *(From - To)*
2 December 2004 - 1 December 2006

**4. TITLE AND SUBTITLE**
Advanced Physics-Based Modeling of Discrete Clutter and Diffuse Reverberation in the Littoral Environment

**5a. CONTRACT NUMBER**
N00014-04-C-0399

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Peter Neumann (PSI)
Charles Holland (ARL/PSU)
Kevin LePage (NRL-DC)

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Planning Systems Incorporated
12030 Sunrise Valley Drive, Suite 400, Reston Plaza 1
Reston, VA 20191-3453

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Office of Naval Research
Attn: Michael Traweek, Code 321 MS
Ballston Tower One
800 North Quincy Street
Arlington, VA 22217-5660

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
In response to the Navy STTR Topic N03-T011, “Physics-based modeling of Acoustic Reverberation in the Littoral Environment,” a team representing PSI, ARL-PSU and NRL-DC was assembled to develop a broadband time series simulation capability for both discrete clutter and diffuse reverberation. This simulation capability is based upon the work by Kevin LePage (NRL-DC), who participated on this STTR as an outside funded resource, and uses the coherent summation of narrow band results using normal mode methods to generate the broadband time series simulations. This high level of simulation fidelity was proposed for use in the AEER (Advanced Extended Echo Ranging) programs as a tool for active, coherent sonar system development. Due to funding limitations in FY 07 at NAVAIR, that transition was not possible even with a high level of interest from the AEER program manager. The product of this Phase II STTR does not replace an existing modeling capability within the proposed program but rather will provide an entirely new simulation capability.

**15. SUBJECT TERMS**
STTR Report, Discrete clutter, diffuse reverberation, littoral environments, high-fidelity modeling, geo-clutter, boundary characterization, scatter mechanisms

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL | 24 | Peter D. Neumann |
| | | | | | **19b. TELEPHONE NUMBER** *(Include area code)* (703) 788-7700 |

Reset

# Advanced Physics- Based Modeling of Discrete Clutter and Diffuse Reverberation in the Littoral Environment
## STTR Phase II - Topic N03-T011

**Peter Neumann**
**Planning Systems Incorporated**
**12030 Sunrise Valley Drive**
**Suite 400, Reston Plaza 1**
**Reston, VA 20191-3453**

**Charles Holland**
**Penn State University**
**Applied Research Lab**
**P.O. Box 30**
**State College, PA 16804-0030**

**Kevin LePage**
**Naval Research Lab**
**Washington, DC 20375-5320**

**Contract Number: N00014-04-C-0399**

**Phase II STTR Final Summary Report**
**Covering December 2, 2004 through December 1, 2006**

**UNCLASSIFIED**

**Issuing Agency:**

**Office of Naval Research**
**Attn: Michael Traweek, Code 321MS**
**Ballston Tower One**
**800 North Quincy Street**
**Arlington, VA 22217-5660**
**(703) 696-4112 (Phone)**
**(703) 696-2007 (Fax)**

# Table of Contents

# List of Figures

## Executive Summary

In response to the Navy STTR Topic N03-T011, “Physics-based modeling of Acoustic Reverberation in the Littoral Environment,” a team representing PSI (Planning Systems Inc.), ARL-PSU (Applied Research Laboratory – Penn State University) and NRL-DC (Naval Research Laboratory – District of Columbia) was assembled to develop a broadband time series simulation capability for both discrete clutter and diffuse reverberation. This simulation capability is based upon the work by Kevin LePage (NRL-DC), who is participating on this STTR as an outside funded resource, and uses the coherent summation of narrow band results using normal mode methods to generate the broadband time series simulations. This high level of simulation fidelity was proposed for use in the AEER (Advanced Extended Echo Ranging) programs as a tool for active, coherent sonar system development. Due to funding limitations in FY 07 at NAVAIR, that transition was not possible even with a high level of interest from the AEER program manager. More details on this attempted transition are provided in the section of this report on “Future Applications of Phase II Work and Products” on page 19.

The product of the Phase II STTR does not replace an existing modeling capability within the proposed programs but rather will provide an entirely new simulation capability. Current modeling tools at low and mid-frequencies (up to 5 kHz), including the Navy standard ASPM (Acoustic System Performance Model) and CASS (Comprehensive Acoustic System Simulation) models, cannot produce a simulated time series or simulate the effect of discrete clutter at the receiver. The development of the R-SNAP simulation tool under this Phase II STTR was intended to augment the in-water testing done on active, coherent sonar systems and to allow more sophisticated in-water testing through the use of simulation during the early design process.

## Phase II Objectives and Technical Approach

The Phase II base program has two primary objectives.

1. Develop a more complete understanding of the physical mechanisms responsible for observed clutter (primary geo-clutter) in available acoustic data sets and develop an approach to model those physical mechanisms within the simulation code framework.
2. Develop a MATLAB based simulation product based upon the prior and current work of Kevin LePage which uses a coherent summation of narrowband normal mode results which will simulate broadband time series from both discrete clutter and diffuse reverberation in a littoral environment. This simulation will be validated against in-water acoustic data sets and will include both documentation of the validation and simulation suitable for use by the targeted transition programs (AEER).

The technical approach for the first objective is the analysis of acoustic data with clutter events to provide a more complete representation of the physical mechanisms responsible for the observed clutter features. The use of measure acoustic data to produce a physical representation of the clutter mechanisms will produce modeling approaches that can be extrapolated to other environments and source/receiver characteristics with a much higher degree of confidence than modeling approaches that utilize empirical descriptions of the clutter mechanisms.

The technical approach for the second objective described above utilizes the modeling approach being developed by Kevin LePage that uses the coherent summation of narrowband normal mode results to generate a simulated broadband time series. The modeling approaches developed for the identified clutter mechanisms will be integrated into this simulation in addition to currently developed modeling for the diffuse reverberation component of the simulated broadband time series. Model-to-data comparisons were performed as the simulation was developed to confirm the correct implementation of the various clutter mechanisms.

## Phase II Base Program Results

The technical objectives described in this report are part of a 24 month Phase II STTR base program. The first section describes the results from the first 12 months of the base program with the second section (beginning on page 13) describing the results from the final 12 months.

### Base Program Results (Months 1-12)

Charles Holland of ARL/PSU has focused his work on the processing and analysis of acoustic data sets from the Boundary 2004 experiment and the observed clutter features that are the results of submarine mud volcanoes in the experiment area (see Figure 1). The analysis of the acoustic data received on the vertical line array (see Figure 2) used a direct path measurement technique which significantly reduced the assumptions[1] present in long-range reverberation observation.

[1] Long-range reverberation observations require an extremely accurate estimate of the bottom loss in order to estimate accurately the target strength of an observed clutter feature.

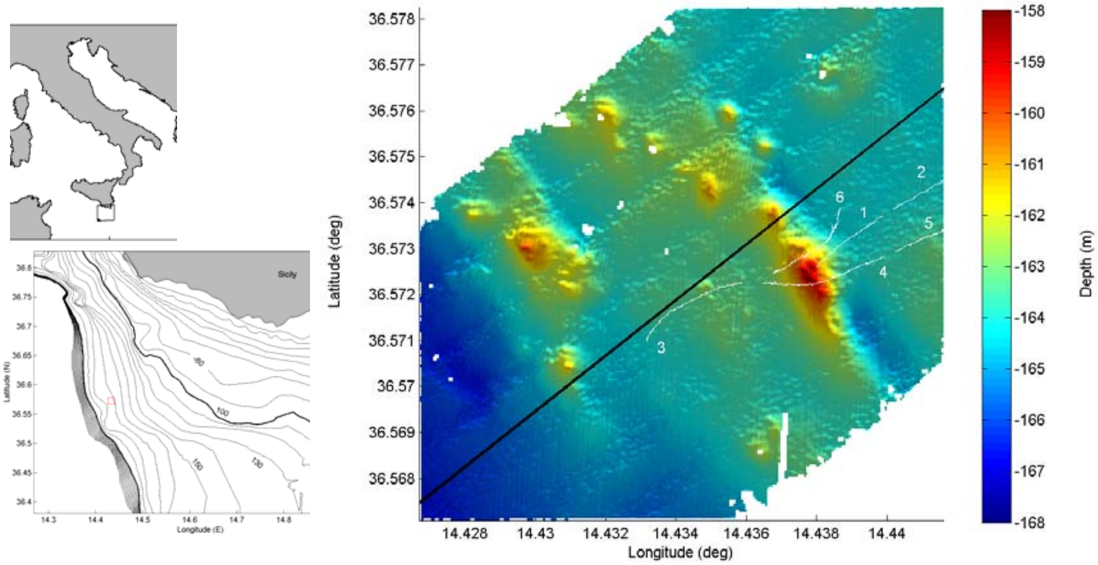


**Figure 1: Boundary 2004 Experiment (May 2004) showing the experiment area with the side-scan sonar track line (solid black line) and experiment track lines (white lines) overlying the bathymetry showing the submarine volcano of interest.**

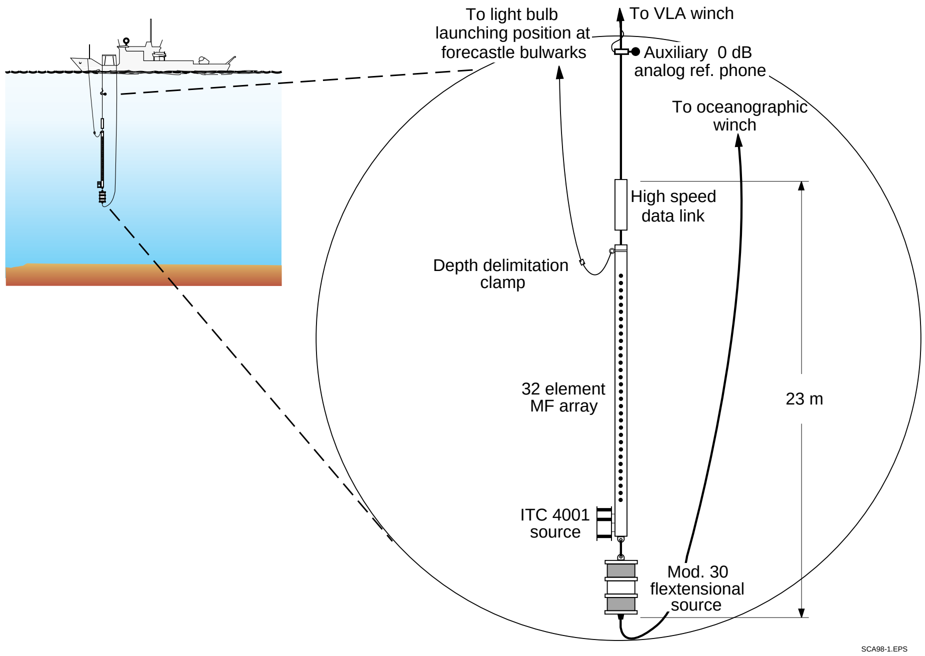


**Figure 2: Transmit and receive system used for the Boundary 2004 experiment data collection.**

This technique (shown in Figure 3) has the potential for direct observation of the clutter feature of interest and can study small scale spatial variability and isolated features, due to the small distances between the source, receiver and the clutter features. This measurement technique requires both a short transmit pulse and a vertical receive array to mitigate the problems of multipath (as shown in Figure 3) and care must be taken to avoid contamination by sub-bottom reflections at normal incidence.

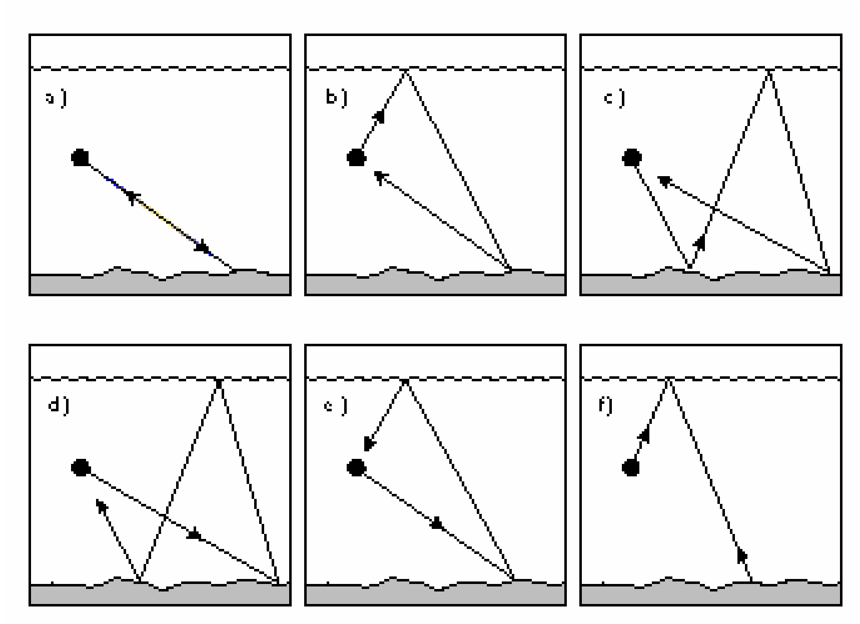


**Figure 3: Diagram showing the direct path measurement technique and the various paths for acoustic energy (path a – direct path source to bottom and back to receiver, path b – path from source to surface, bottom and receiver, etc.).**

An example of the acoustic data from this experiment is shown in Figure 4. The results show the vertical line array data (vertical receive angle versus time) paired with a diagram showing the various ray path combinations with the black arrows highlighting the clutter feature for each ray path combination in the processed acoustic data. The analysis of this data uses the sonar equation to compute the target strength of the clutter feature. This requires estimates of the transmission loss along each of the paths (shown in Figure 3) as well as estimates of the reflection loss at the bottom and surface. Unlike long-range reverberation measurements where small errors in the boundary reflection loss are magnified due to the large number of boundary interactions, reflection loss errors have significantly less effect on the direct path measurements used in this data analysis due to the limited number of boundary interactions.

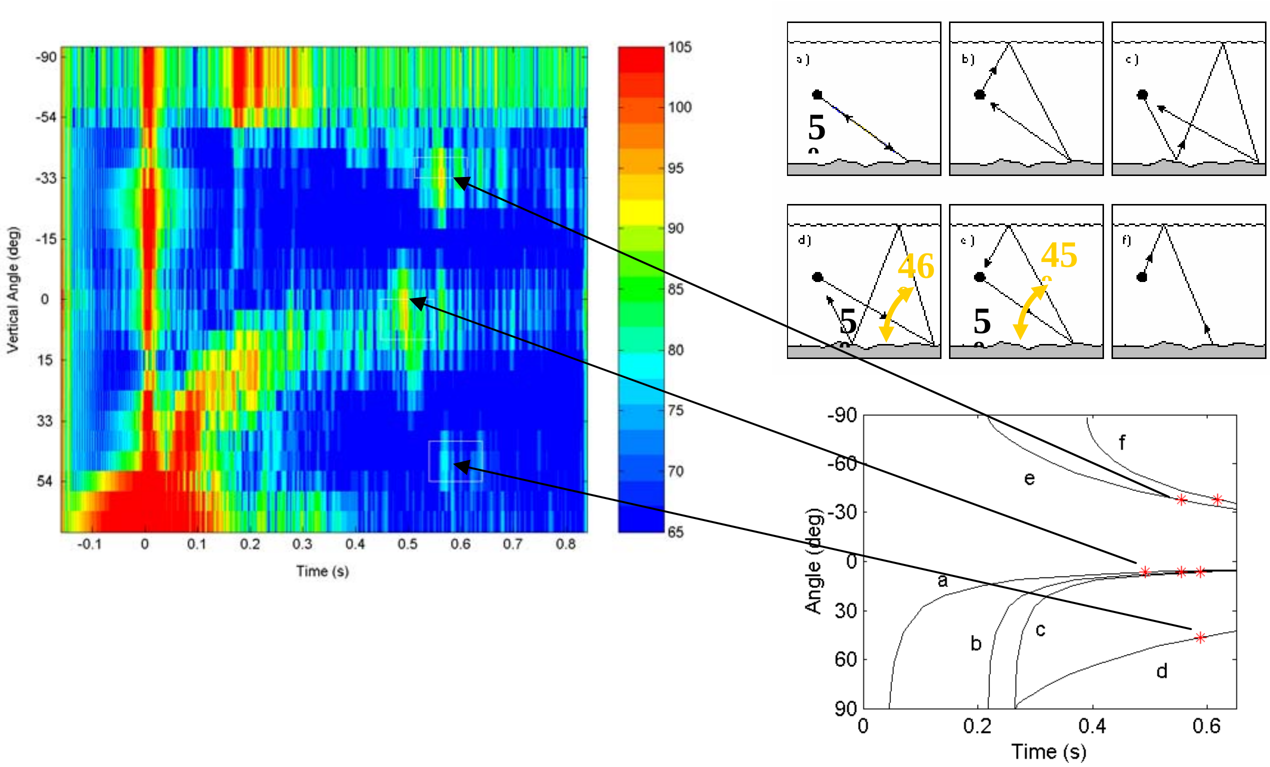


**Figure 4: Scattering at 1800 Hz (vertical receive angle versus time) showing the submarine mud volcano clutter feature (marked by the black arrows).**

This work has produced estimates of the target strength for the submarine volcanoes as a function of frequency in both monostatic and a vertically bistatic geometry. The information gained from this analysis is presented in Figure 7 of this summary report.

Kevin LePage of NRL-DC has been working on providing a more rigorous understanding of the physical mechanisms responsible for long-tailed (non-Rayleigh, clutter-like) reverberation in littoral environments. This work was initially presented the ASA meeting in Vancouver, B.C. in May 2005. The goal of this work is to estimate the non-Rayleighness of littoral reverberation as a function of the active sonar system (frequency, bandwidth and beam pattern), the environment (sound speed profile and bottom properties) and the scatterers (amplitude and spatial distribution). The approach developed by Kevin LePage has been to use a $X_1^2$ (Chi squared with one degree of freedom) distribution for the two and four point correlation function to compute the second moment of the reverberation intensity. The mathematical derivation of his work requires considerably more space than is available in this summary report. Interested readers are invited contact Kevin LePage directly using the contact information on the first page of this report.

A simulation result for 75 and 750 Hz shown in Figure 5 illustrate several of the capabilities of this work. For correlation lengths less than a wavelength, the reverberation intensity (top row in Figure 5) is not a function of correlation length. The standard deviation (middle row in Figure 5) increases with increasing correlation lengths due to fewer scatterers in the illuminated bottom

patch and decreases as time increases due to a larger number of bottom patches being illuminated due to waveguide dispersion. The ratio of the standard deviation of the reverberation to the reverberation intensity (bottom row in Figure 5) increases as the correlation length increases due to the number of scatterers in the bottom patch decreasing.

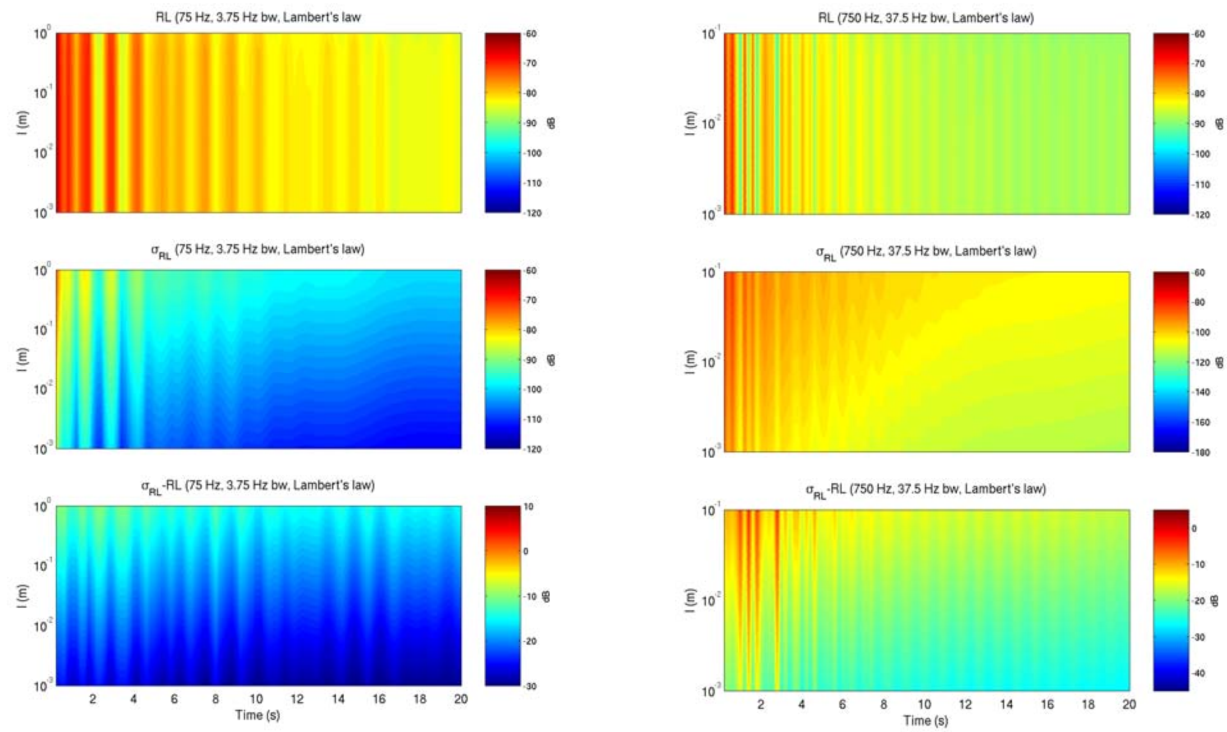


**Figure 5: Simulation results for 75 Hz (left) and 750 Hz (right) showing the reverberation intensity (top row), reverberation standard deviation (middle row) and ratio of the two (bottom row) as a function of correlation length (y-axis) and time (x-axis).**

This result is shown in more detail in Figure 6 where the ratio of the standard deviation to the intensity at 10 seconds is plotted versus the correlation length. The ratio of the standard deviation to the reverberation intensity becomes very large as the number of scatterers in the bottom patch approaches one (correlation length scales of 10 m for 3.75 Hz of bandwidth at 75 Hz, or patch size of 200 m; and correlation length scales of 1 m for 37.5 Hz of bandwidth at 750 Hz, or patch size of 20 m).

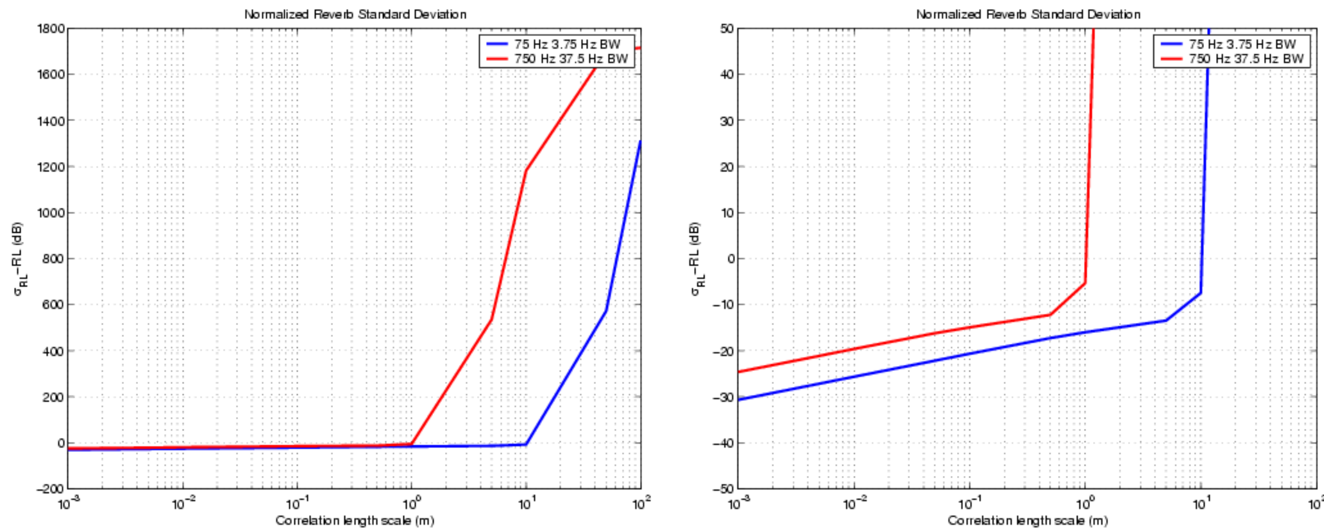


**Figure 6: Normalized reverberation standard deviation at 10 seconds plotted versus frequency (75 and 750 Hz) and correlation length.**

The analysis of the Boundary 2004 experiment data by Charles Holland produced both estimates of the target strength from single mud volcanoes and a clearer understanding of the scattering mechanism responsible for the observed clutter features in the acoustic data. The target strength estimates shown in Figure 7 are for 800, 1800, 2400 and 3600 Hz for path a (solid blue line), path e (solid red line) and path d (dashed green line). These are target strength measurements from a single mud volcano and they provide several insights into the physical scattering mechanism responsible and the most plausible modeling approach. The target strength estimates for 1800 and 3600 Hz for path a and path e show a target strength of 6 to 12 dB that does not appear to be a facet scattering mechanism as there is little difference between the different scattered angles at these frequencies. The noticeable difference between the target strength estimates at 2400 Hz is not currently understood and will be investigate further in the second year.

The acoustic data and the analysis peformed to date does not indicate any evidence of mud volcanoe induced scattering from within the water column, either from methane ebullition or from effluent particulates in the water column. The observed target strengths could be fit using a bubble size distribution (within the sediment) to the frequency dependent target strength. However, Charles Holland believes that the simplest, and most plausible, explanation for the observed scattering is that it is the result of scattering from inhomogeneities within or at the interface of the mud volcano itself which is composed of mud breccia or carbonate. Regardless of the modeling approach adopted for mud volcano features of this type, it is clear that their measured target strength of 6 to 12 dB indicates that they can be a significant source of clutter for an active sonar system operating in littoral environments with gassy sediments.

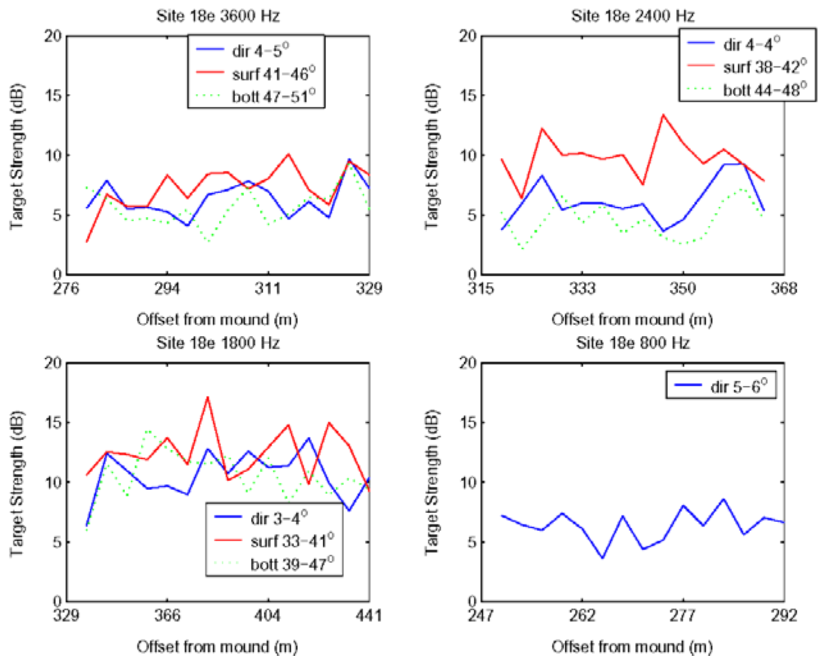


**Figure 7: Estimated target strength at 800, 1800, 2400 and 3600 Hz using path a (see Figure 3) shown by the solid blue line, using path e shown by the solid red line and path d shown by the dashed green line.**

The model-to-data comparison described in the objectives section of this report began with a data set (shown in Figure 8) from the SCARAB 98 experiment that used a SUS source and a towed line array receiver. A model-to-data comparison for beam 36 (77.26 deg) from forward end-fire (heading 19.5 degrees NNE) is shown in Figure 9 (time series) over the band 100 to 1150 Hz compared to the data over the 0 to 1800 Hz band. As we move forward we will refine this model data comparison using Holland's estimates of the frequency dependent sediment scattering coefficient, Ragusa ridge scattering coefficient and ship target strength. The lack of registration between the ship position in the simulation and the data is due to an error in estimating the ship range. The lack of registration between the Ragusa ridge returns in the data and the simulation may be due to an error in the estimate of the ridge in the simulation inputs or in the assumed position of the ship.

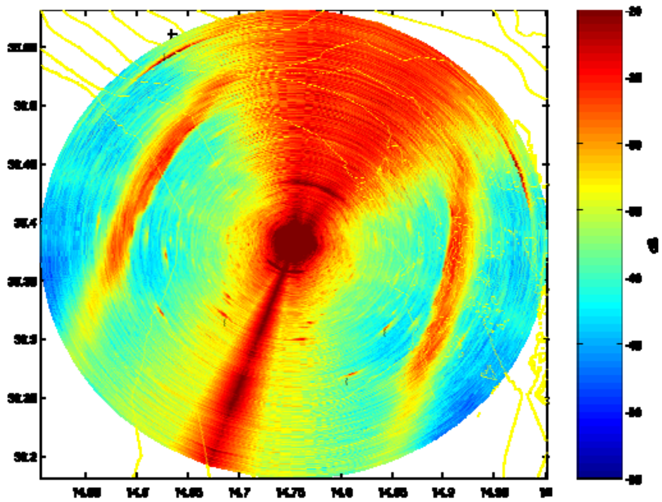

Figure 8: **The beam time series of the smoothed SUS response from SCARAB 98, including the Campo Vega rig (late time, NNW), and the three wreck sites (the three other black crosses to the SE, SSE and SW).**

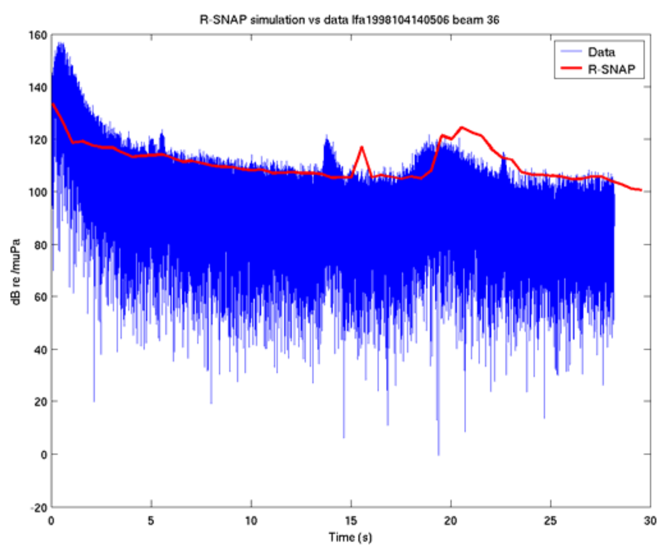


Figure 9: **SCARAB 98 model-to-data time series comparison for beam 36 (100 to 1150 Hz for the model and 0 to 1800 Hz for the data).**

The time-frequency of the data and the simulation are shown side by side in Figure 10. The simulation was run every 500 ms for a frequency spacing of $f/20$ Hz (i.e. at 100 Hz, the frequency spacing of the simulation is 5 Hz, while at 1000 Hz it is 50 Hz.). The striation pattern of the data is visible in the simulation, although at much lower resolution due to the large time steps, also, the frequency independent basement scattering mechanism for the Ragusa ridge seems to under-estimate the scattering from this feature at higher frequencies. Finally, the

simulations do not accurately model the high levels at early time where normal mode propagation ignores the high angle early time returns above the critical angle, and the levels seem too high at late time and higher frequencies.

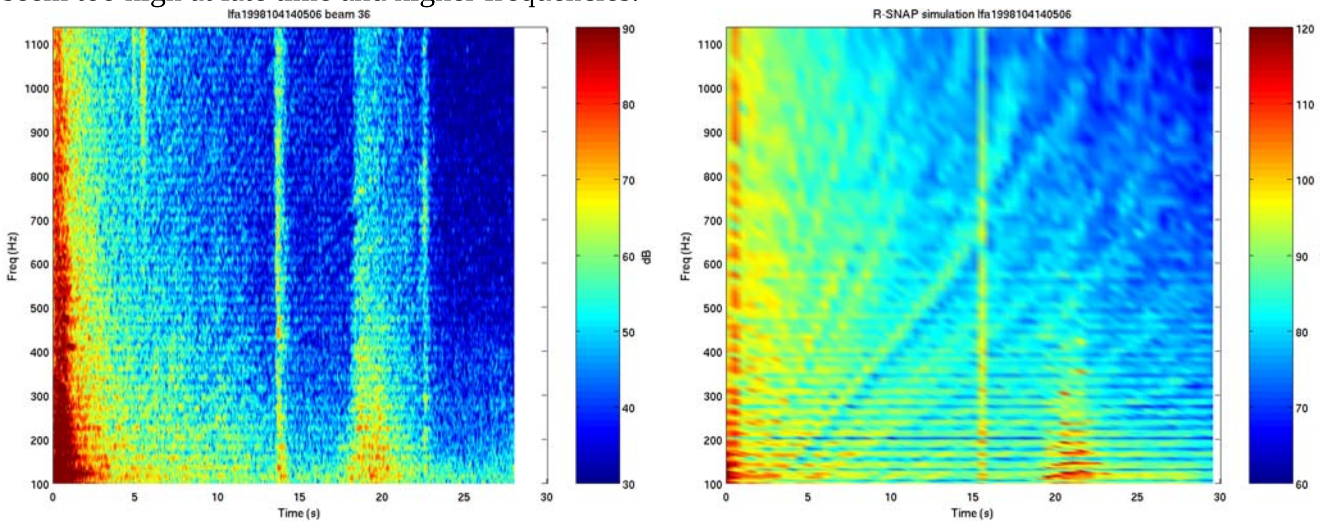


**Figure 10: SCARAB 98 model-to-data comparison for beam 36 for 100 to 1150 Hz.**

**Base Program Results (Months 13-24)**

The most significant tasks completed during the last 12 months are listed below with technical details provided in the results section of this report.

1. Charles Holland provided environmental properties for the Malta Plateau are where the reverberation and clutter data was collected. These environmental properties were derived from independent methods avoiding the circular approach of using acoustic data to both estimate the environmental properties and validate the model. The use of independent methods greatly increased the confidence in the environmental properties provided to the R-SNAP simulation.
2. Kevin LePage produced the R-SNAP simulation results for the SCARAB 98 data sets from the Malta Plateau. These results included broadband simulation results which were presented at the NAVAIR brief in April 2006. The R-SNAP results showed that simulation of both diffuse reverberation and discrete clutter in a littoral environment was possible given detailed environmental information covering frequencies from 100 to 1,150 Hz.
3. Peter Neumann has led the effort to transition the R-SNAP simulation to the AEER program at NAVAIR. He coordinated the brief in April 2006 and was responsible for the follow-up dialog between the AEER program manager and ONR TPOC. As discussed in the transitions section of this report, it now appears that budgetary limitation within the AEER program for FY 07 will prevent this transition from occurring in 2007. He has also continued to work with Kevin LePage on the documentation and user's guide for the R-SNAP simulation.

Technical details on the work by Charles Holland and Kevin LePage are provided in the following paragraphs of this report. Details on the proposed transition of the R-SNAP simulation to the AEER program are provided later in this report under the future applications section of this report.

During late 2005, Charles Holland of ARL/PSU focused his efforts on providing the environmental inputs required for the R-SNAP simulation at the Malta Plateau data site. He provided the Lambert scattering strength parameters, instead of the Lommel-Seeliger scattering kernel parameters, for the Malta Plateau. During the same time period, he conducted an analysis using vertical line array data to estimate independently the reflection coefficient as a function of frequency. The reflection coefficient values closely match those previously obtained using transmission loss data. In early 2006, Charles Holland's work moved to the scattering data from an underwater ridge, which produces the observed clutter, to obtain a frequency dependent estimate of scattering strength. Work in February showed that the azimuthal dependence of the scattering strength appears to follow roughly Lambert's Law.

With the environmental parameters for the Malta Plateau provided to Kevin LePage (NRL-DC), Charles Holland moved on to analyses of long-range reverberation data. At ranges of 18-22 km, the returns from mud volcanoes were found to be 10-15 dB above the background reverberation level yielding target strengths of 2-16 dB over the frequency range 160-1400 Hz. These target strengths are very similar to those measured by short-range, direct path measurements, giving confidence to the measurement and analysis techniques. The new results extend the frequency range of the observed target strengths two octaves below prior observations.

Charles Holland presented a summary of his work at the brief presented at NAVAIR in April 2006. He provided a clear overview of the process he has developed which provides independent estimates of the environmental properties used as the inputs to the R-SNAP simulation. This process is an important element of this work as it avoids the circular approach where reverberation data is used to estimate the environmental properties which are then used to validate the simulation. Using independent methods for estimating the environment provides a much higher degree of confidence in the model-to-data comparisons compares to the circular approach.

Kevin LePage of NRL-DC created a model-to-data comparison for the SCARAB 98 data set provided by Charles Holland. Kevin was able to show comparisons with the data as a function of bearing and range for 350 Hz (shown below in Figure 11) and 1 kHz. These comparisons showed the capabilities of the R-SNAP simulation when detailed environmental information is provided. At the SCARAB 98 experiment site, the thick sediment present near the source location became thinner, in particular bearings, eventually giving way to a higher impedance basement which broached the sea bed along a ridge to the southeast and east.

Of most significance to the NAVAIR audience at the April 19th brief were the comparisons of the time series between the measured data and the R-SNAP simulation. Kevin produced results for both 350 Hz and 1 kHz (shown in Figure 12) and included audio files (WAV format) in his slides that were played at the brief on April 19th to illustrate the results. Time-frequency plots for

the measured data and the R-SNAP simulation for both 350 Hz (shown in Figure 13) and 1 kHz (shown in Figure 14).

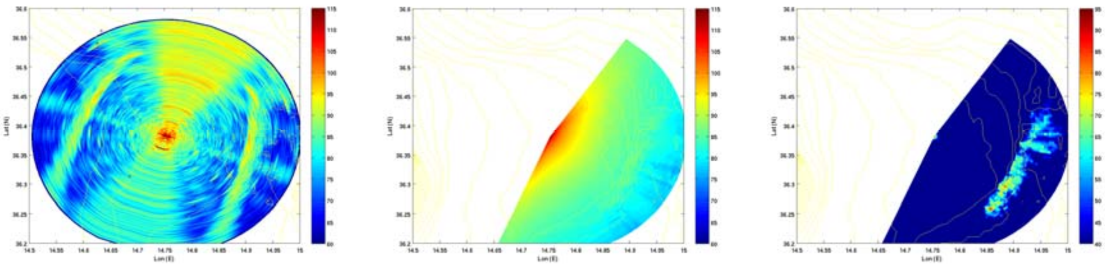

**Figure 11: Model-to-data comparison with SCARAB 98 data at 350 Hz. Measured data shown in left panel, R-SNAP prediction for bottom scattering shown in middle panel and R-SNAP prediction for sub-bottom scattering shown in right panel.**

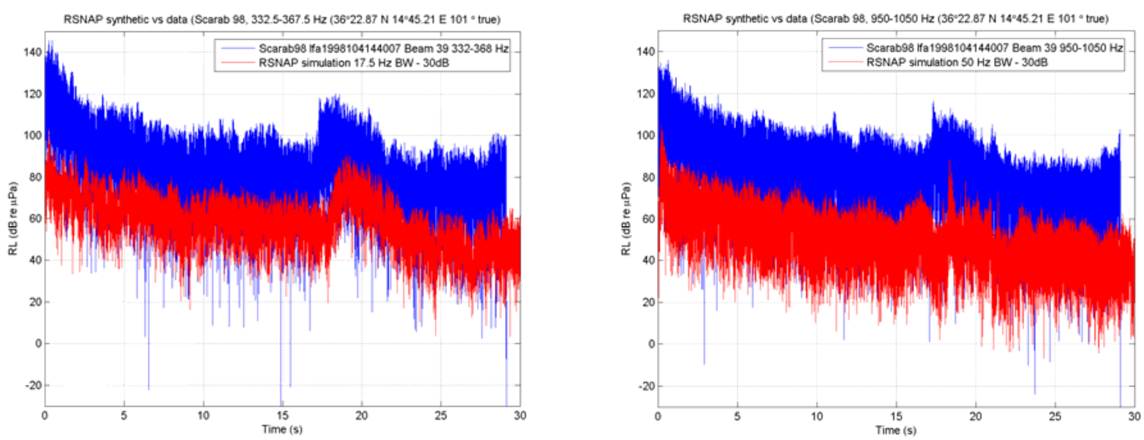


**Figure 12: Model-to-data comparisons with SCARAB 98 data at 350 Hz (left panel) and at 1 kHz (right panel). Measured time series data is shown in blue with R-SNAP simulation shown in red (shifted 30 dB lower to allow for visual comparison between the data and the simulation).**

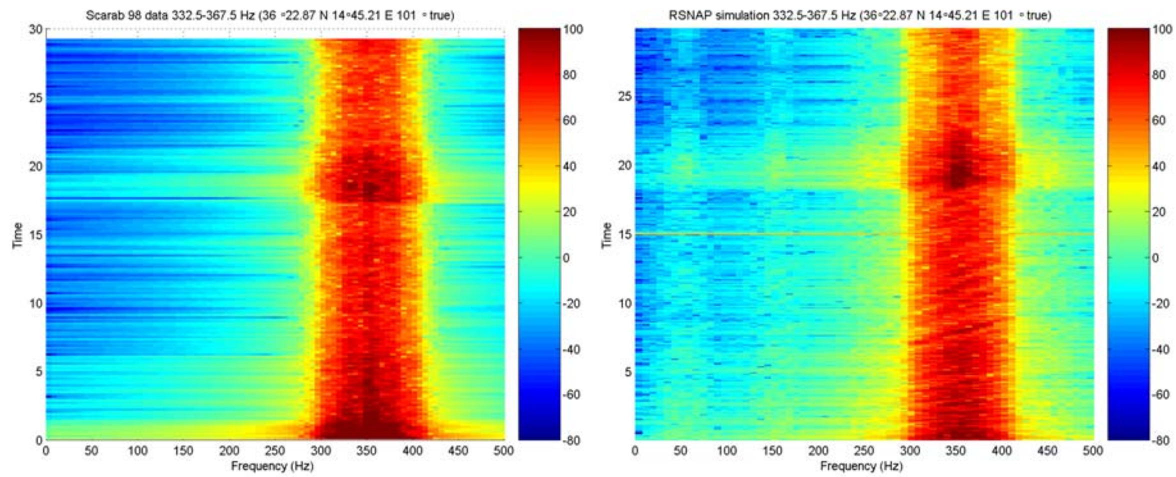


**Figure 13: Time-frequency plots for the 350 Hz data showing the measured data (left panel) and the R-SNAP simulation (right panel).**

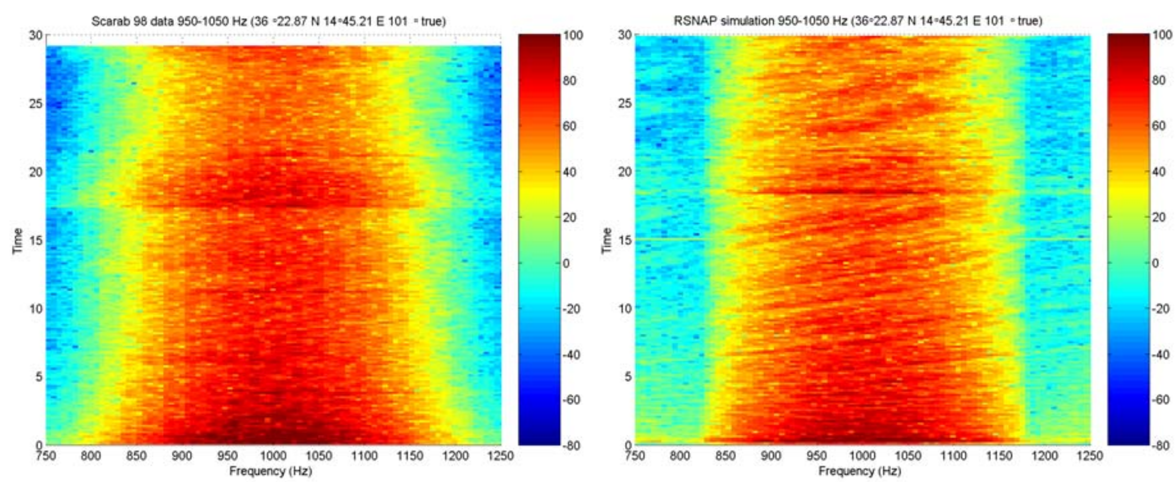


**Figure 14: Time-frequency plots for the 1 kHz data showing the measured data (left panel) and the R-SNAP simulation (right panel).**

A comparison across a band from 100 Hz to 1.15 kHz between the SCARAB 98 beam data and the R-SNAP simulation was also presented (shown in Figure 15) showing the capability of the R-SNAP simulation to produce broadband simulations (much greater than 10% of the center frequency). The striation pattern visible in the narrowband results in Figure 13 and Figure 14 is clearly visible in the data and simulation in Figure 15.

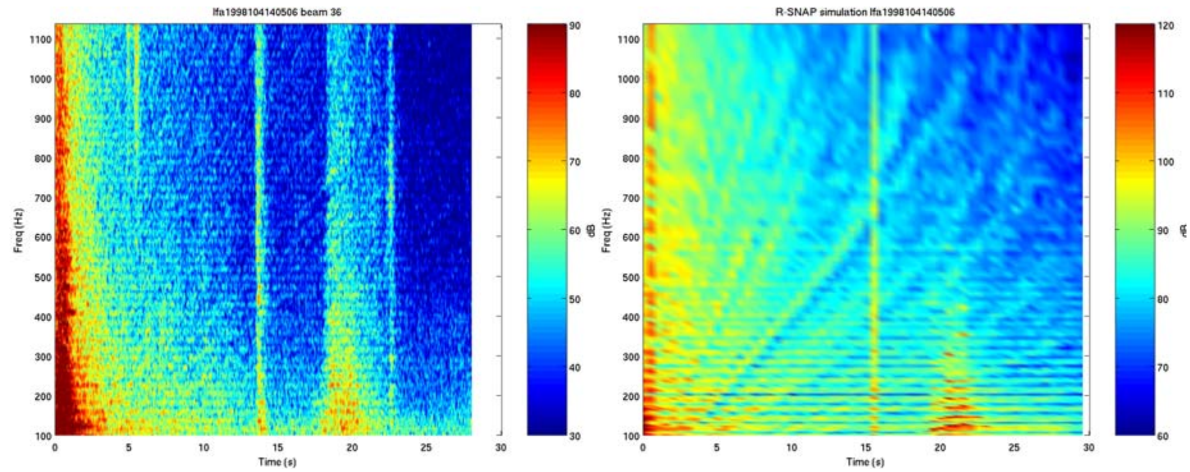


**Figure 15: Model-to-data comparison covering 100 Hz to 1.15 kHz.**

Through the summer of 2006, Charles Holland worked on processing broadband transmission loss data which is required to analyze the frequency dependence of the clutter target strength. He also began to investigate the temporal and spatial stability of the observed clutter. Qualitatively the clutter looks similar over short time/space scales.

Most recently Doug Abraham of ARL-PSU has looked at the spatial distribution of the mud volcanoes to determine if their spatial locations might induce an active sonar target tracker to initialize a track. A small region of bathymetric data was analyzed to give insight into the locations of mud volcanoes relative to fault lines. A potentially significant finding from this analysis was that the height of the mud volcanoes above the local seabed is represented well by an exponential probability density function. Insight from this analysis was used to create simulation algorithms for fault lines and mud volcano locations relative to the fault lines. A simple track initialization test statistic was derived to evaluate how likely sonar detections of the mud volcanoes would be to form a target track. The test statistic was compared with that generated by a homogenous Poisson process (spatially uniform clutter) and a target with linear motion and Gaussian measurement errors. The track initialization statistic clearly separated the target and Poisson process detections; however, the mud volcano fields produced a range of values with many to most of them likely to initiate a false target track. The most sensitive parameter in the mud volcano field simulation was the aspect ratio (width to height) where making this large caused mud volcanoes to exist far from the fault and therefore reduce the likelihood of producing a false target track.

## Phase II Option and Bridge Option Tasks

At the conclusion of this Phase II STTR base program, it does not appear that the Phase II STTR option and bridge option tasks will be funded. To provide the report reader an overview of the planned future work for the STTR, a brief summary of these tasks is provided.

The two Phase II option tasks were designed to add additional capabilities to the simulation package developed under the Phase II base program. The Phase II option program Task 1 would augment the modeling capability of the simulation with an ability to model the frequency spread

due to interaction with the sea surface. The Phase II bridge option Task 1 was designed to transition the mature simulation product to an identified end user and make the necessary modification and/or additions to the simulation to satisfy the end-user's particular requirements.

***Phase II Option Program – Task 1 – Modeling of Frequency Spread due to Surface Scattering***

Under the Phase II option program Task 1 the ability to model the frequency spread resulting from the interaction with the air-water interface and the near-surface bubble clouds will be added to the model developed under the Phase II base program. The approach does not look to conduct basic research on this effect but looks to transition the results developed to date (including those from NRL-DC, Gragg, 2003) into the model.

*Products from Phase II Option Program Task 1*

The product from the Phase II option program Task 1 would be a modified version of the model developed under the Phase II base program with the added capability of including the frequency spread in the received signal caused by interaction with the air-water interface and the near surface bubble clouds. The changes to the model would also be reflected in an updated set of documentation following the same format of the documentation created under the Phase II base program Task 4.

*Timetable and Personnel for Phase II Option Program Task 1*

The timetable for the Phase II option program Task 1 would be a period of performance of 12 months starting near or at the completion of the Phase II base program period of performance. Peter Neumann of PSI will be the lead investigator for this task with work being done at PSI in conjunction with experts in the field at NRL-DC. The costing for this task provides for 1350 hours of labor for Peter Neumann (PSI) who will be the sole performer on this task.

***Phase II Bridge Option Program – Task 1 – Modifications/Additions to Simulation Package for the AEER, LAMP or other end-user Program***

The transition of the simulation package developed under this STTR to the AEER, LAMP or another program is expected to require some additional modifications to simulation to satisfy the particular program requirements. These modifications could include the addition of specific beamforming routines as was noted by the EER program or could include additional model-to-data comparisons to validate the simulation for a particular program or environment. The exact tasking would be defined between the ONR TPOC for this STTR, the end-user program and PSI.

*Products from Phase II Bridge Option Program Task 1*

The product for the Phase II bridge option Task 1 would be a modified version of the simulation developed under the Phase II base and option program with the additional elements required by the end-user program. The additions to the model necessary for this task would also be reflected in an updated set of documentation following the same format of the documentation created under the Phase II base program Task 4.

*Timetable and Personnel for Phase II Bridge Option Program Task 1*

The timetable for the Phase II option program Task 1 would be a period of performance of 6 to 9 months starting near or at the completion of the Phase II base program period of performance. Peter Neumann of PSI will be the lead investigator for this task with work being done at PSI in conjunction with experts from the end-user program. The costing for this task provides for 860 hours of labor for Peter Neumann (PSI) who will be the sole performer on this task.

## Future Applications of Phase II Work and Products

The ability to simulate broadband time series at the receiver (monostatic or bistatic) in an active sonar system including the effects of both discrete clutter and diffuse reverberation will be a new capability for the sonar system designer. The simulation package being developed under this Phase II STTR will not replace in-water testing but should allow the sonar designer to test early designs with the simulation, instead of in-water, with the result being a reduction in the development costs (simulation costs are expected to be less than in-water testing costs). The simulation will also allow sonar designer to test hypothetical sonars in environments against particular types of discrete clutter with a degree of control that cannot be achieved through in-water testing.

### Proposed Transition to AEER Program in FY 07

Beginning with a brief at NAVAIR (Pax River NAS) in December 2003, a transition to the AEER (Advanced Extended Echo Ranging) program was being promoted. The 2003 brief allowed the Phase II STTR option tasks to be refined to reflect the needs of a transition to the AEER program emphasizing the need for the effect of sea surface interaction, most notably the resulting frequency spread, to be included in the simulation. A brief in April 2006 to the AEER program manager, Rick Fillhart, at NAVAIR provided him with details on the work completed under the Phase II STTR base program to date and highlighted the potential uses of the simulation product under development to his program’s particular needs. The AEER program is exploring the use of a coherent source which will allow for considerably more sophisticated signal processing than is currently used with incoherent sources. As previously noted in this report, there is no existing tool for use in active sonar system development to provide a simulated time series that includes the effect of both diffuse reverberation and discrete clutter.

The positive feedback received at the brief included discussions of other potential uses for the simulation including as a stimulation source for trainer simulators. The need for real-time interaction by a user would require a considerable effort to implement the simulation on a distributed processor architecture. An eight processor machine at NAVAIR was discussed as a possible host platform for this type of development work.

Following discussions held in the months following the April 2006 brief, NAVAIR struggled to identify funding in their FY 07 budget to match the ONR funding for the Phase II option task. In mid-September we were notified by Rick Fillhart that funding for the transition of the R-SNAP simulation product to the AEER program was not available in FY 07. At the time this report was written the current status of this effort is that the proposed transition to the AEER program will not go forward at the conclusion of the Phase II STTR base program in December 2006.

## Related Projects

This section summarizes the related projects that key personnel on this Phase II STTR have participated in during the 24 month period of performance of this Phase II STTR.

- Charles Holland of ARL/PSU is currently participating in the ONR GeoClutter Program which is providing measurements and analyses results from a May 2004 experiment in the Straits of Sicily that are being leveraged into this Phase II STTR to enhance the development of the broadband simulation product. Dr. Holland is also working on the Boundary Characterization Joint Research Project (ONR and NURC) providing acoustic, geoacoustic, geologic and geophysical data for the Straits of Sicily.
- Kevin LePage, through the completion of FY 06, has been funded under the NRL Multistatic Active System Performance exploratory research initiative, where he has continued the model development of C-SNAP and BiStaR. In this work he has collaborated closely with Chris Harrison of NURC, benchmarking diffuse reverberation levels for range dependent scenarios.
- Charles Holland and Kevin LePage are both participating in the Broadband Clutter Initiative Joint Research Project ONR/NRL/DRDC-A/NATO Undersea Research Centre (2006-2009): This project has goals that are closely connected with the above project.

## Publications, Briefs, Reports and Travel

The following is a summary of the publications (both published and submitted) during the 24 months of this Phase II STTR by the key personnel.

- Holland, C. W., T. Weber and G. Etiope, "Acoustic Scattering from Mud Volcanoes and Carbonate Mounds," *Journal of the Acoustical Society of America* (accepted for publication in August 2006).
- Holland, C. W., "Constrained comparison of ocean waveguide reverberation theory and observations," *Journal of the Acoustical Society of America*, **120** (4), 1922-1931 (2006).
- Holland, C. W., "Mapping seabed variability: Rapid surveying of coastal regions," *Journal of the Acoustical Society of America*, **119** (3), 1373-1387 (2006).
- Holland, C. W., "On errors in estimating seabed scattering strength from long-range reverberation," *Journal of the Acoustical Society of America*, **118** (5), 2787-2790 (2005).
- LePage, K. D., "Environmental effects of waveguide uncertainty on coherent aspects of propagation, scattering and reverberation," *IEEE Journal of Oceanic Engineering* [refereed, submitted].
- LePage, K. D., P. Neumann and C. W. Holland, "Broad-band time domain modeling of sonar clutter in range dependent waveguides," *Oceans 2006, Revolutionizing Marine Science and Technology*, 18-21 Sept. 2006, Boston, MA.
- LePage, K. D., "Modeled and measured characteristics of non-Rayleigh reverberation," BOUNDARY JRP meeting, NATO Undersea Research Centre (12-14 September 2005).
- LePage, K. D., "Higher moment estimation in physics-based reverberation modeling," Joint ONR 321US and NRL Active Sonar ASW D&I Program Review, Naval Research Laboratory, Washington DC (30-31 August 2005).

The following is a summary of the briefs and reports (sorted by date) by key personnel during the 24 months of this Phase II STTR.

- Kevin LePage presented his paper "Effect of multipath propagation on reverberation statistics in shallow water" at the ASA meeting in San Diego, CA on November 16th, 2004.
- Tom Weber in collaboration with Charles Holland and Giuseppe Etiope presented his paper "Observations of a geoclutter feature in the Straits of Sicily" at the ASA meeting in Vancouver, B.C. on May 17th, 2005.
- Charles Holland in collaboration with Tom Weber and Giuseppe Etiope presented his paper "Close-range acoustic scattering from mud volcanoes" at the ASA meeting in Vancouver, B.C. on May 17th, 2005.
- Kevin LePage presented his paper "Higher moment estimation for shallow water reverberation" at the ASA meeting in Vancouver, B.C. on May 20th, 2005.

- Peter Neumann presented a brief on this STTR at the ONR Code 321MS annual program review in Newport, RI on August 16th, 2005.
- The fiscal year 2005 report for ONR Code 321MS was submitted by email to Jim Holt and Todd Brunori on September 30th, 2005.
- Kevin LePage presented “Non-Rayleigh Reverberation Prediction for Shallow Water Waveguides” at the ASA meeting in Minneapolis, MN on October 21st, 2005.
- The first-year summary report for the Phase II STTR was submitted on December 8th, 2005.
- Peter Neumann, Charles Holland and Kevin LePage briefed Rick Fillhart and other representatives of NAVAIR at Pax River NAS on April 19th, 2006.
- Peter Neumann presented a brief on this STTR at the ONR Code 321MS annual program review in Newport, RI on August 15th, 2006.
- Kevin LePage presented the paper titled “Broad-Band Time Domain Modeling of Sonar Clutter in Range Dependent Waveguides” at the MTS/IEEE Oceans 2006 meeting on September 20th, 2006.
- The fiscal year 2006 report for ONR Code 321MS was submitted by email to Jim Holt and Todd Brunori on October 2nd, 2006.

The following is a summary of the travel by key personnel during the 24 months of this Phase II STTR.

- Peter Neumann traveled to the 2005 ONR Code 321MS annual program in Newport, RI (August 16th – 18th, 2005).
- Peter Neumann and Kevin LePage traveled to ARL/PSU (State College, PA) to meet with Charles Holland on November 22nd, 2005 to plan the goals and tasking for the second year of this Phase II STTR.
- Peter Neumann, Charles Holland and Kevin LePage traveled to Pax River NAS, MD to brief representatives of NAVAIR on the possible transition of the R-SNAP simulation to the AEER program (April 19th, 2006).
- Peter Neumann traveled to Arlington, VA for the ONR TAP (Transition Assistance Program) meeting (July 10th, 2006).
- Peter Neumann met with Michael Traweek (ONR TPOC) at ONR to discuss the potential transition of the product of this STTR to NAVAIR (July 11th, 2006).
- Peter Neumann traveled to the 2006 ONR Code 321MS annual program review in Newport, RI (August 15th, 2006).

## Funding Expended during 24 Month Phase II Base Program

The following is a summary of the funding expended by month during the 24 months of this Phase II STTR. The funding for ARL/PSU as a subcontractor to PSI is shown in parentheses for each month.

- December 2004 - $2,192 ($ 0)
- January 2005 - $2,042 ($ 0)
- February 2005 - $13,761 ($7,286)
- March 2005 - $9,403 ($5,051)
- April 2005 - $7,254 ($4,449)
- May 2005 - $23,246 ($19,768)
- June 2005 - $14,527 ($1,183)
- July 2005 - $18,220 ($7,155)
- August 2005 - $18,596 ($ 0)
- September 2005 - $28,472 ($8,926)
- October 2005 - $22,634 ($ 8,566)
- November 2005 - $18,909 ($6,132)
- December 2005 – $28,596 ($12,340)
- January 2006 – $13,825 ($ 0)
- February 2006 – $25,567 ($11,833)
- March 2006 – $15,185 ($ 0)
- April 2006 – $14,110 ($ 0)
- May 2006 – $54,701 ($38,263)
- June 2006 – $21,817 ($11,318)
- July 2006 – $18,202 ($8,889)
- August 2006 – $33,006 ($22,028)
- September 2006 – $30,304 ($21,361)
- October 2006 – $20,013 ($12,691)
- November 2006 – $20,735 ($10,506)
- December 2006 – $16,565 ($12,395)
- January 2007 - $4,112 ($3,666)

## Report Preparation

This report was prepared and submitted by the following individuals:

Peter Neumann
Planning Systems Incorporated
290 Village Park Drive
Lebanon, OH 45036-7885
(513) 228-0073 (Phone)
pneumann@plansys.com (Email)

Charles W. Holland
The Pennsylvania State University, Applied Research Laboratory
P. O. Box 30
State College, PA 16804-0030
(814) 865-1724 (Phone)
cwh10@psu.edu (Email)

Kevin LePage
Naval Research Laboratory
Washington, D.C. 20375-5350
(202) 404-4834 (Phone)
kevin.lepage@nrl.navy.mil (Email)